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[54] **DUAL LAYER RESONANT QUADRIFILAR HELIX ANTENNA**

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[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[5] **H01Q 1/36; H01Q 21/20**

[52] **U.S. Cl.** **343/895;** 343/850

[58] **Field of Search** 343/895, 908, 796, 850, 343/853, 858

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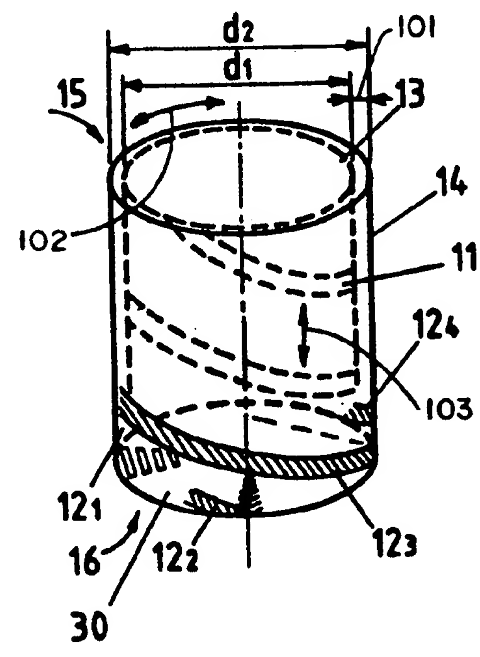
[57] **ABSTRACT**

Disclosed is a new antenna structure having a quasi-hemispherical radiation pattern and capable of having a relatively wide passband, so that it is possible to define two neighboring transmission sub-bands therein or, again, a single wide transmission band. The antenna is of the type comprising a quadrifilar helix (**11**) formed by two bifilar helices (**11$_1$, 11$_2$, 11$_3$, 11$_4$**) positioned orthogonally and excited in phase quadrature, and including at least one second quadrifilar helix that is coaxial and electromagnetically coupled with said first quadrifilar helix (**11**). Preferred application to L band communications among geostationary satellites or transiting satellites with moving bodies fitted out with such antennas.

15 Claims, 4 Drawing Sheets



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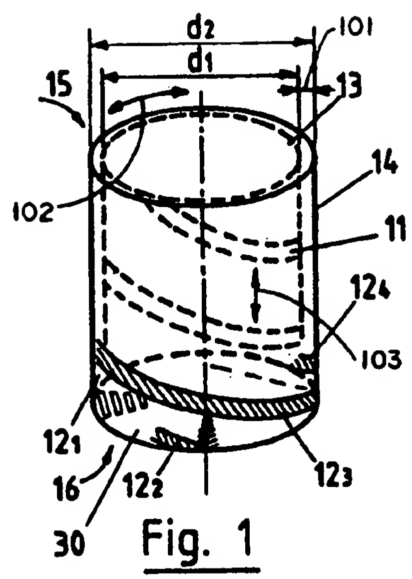


Fig. 1

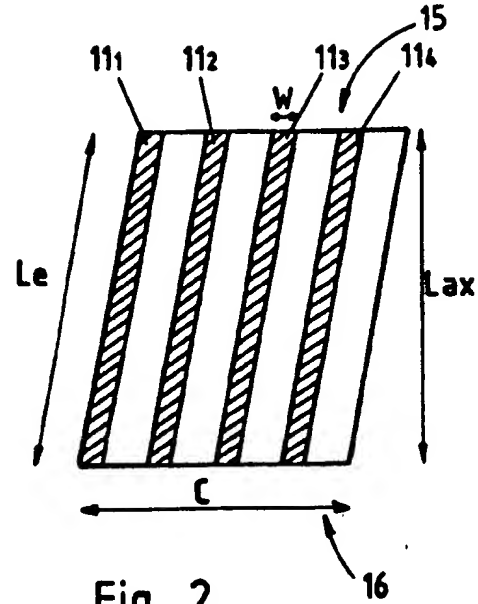


Fig. 2

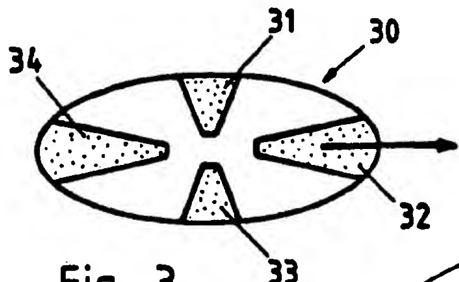


Fig. 3

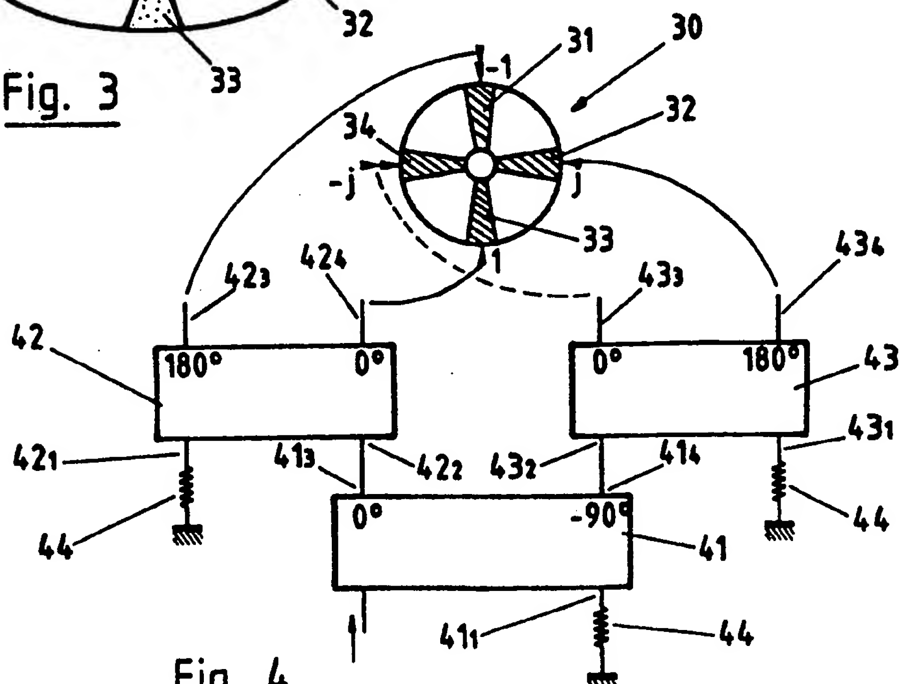


Fig. 4

Fig. 5

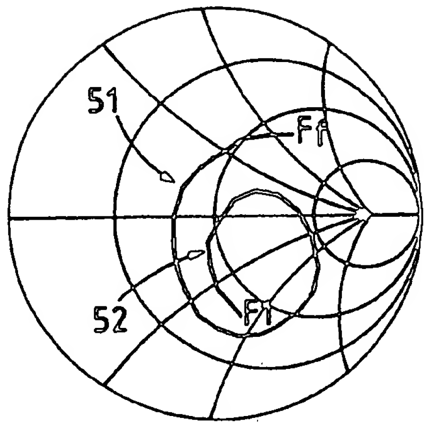


Fig. 6

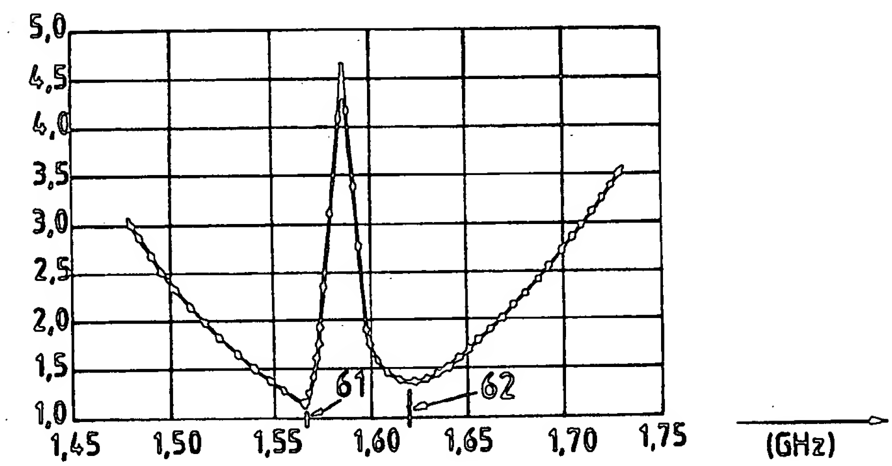


Fig. 7

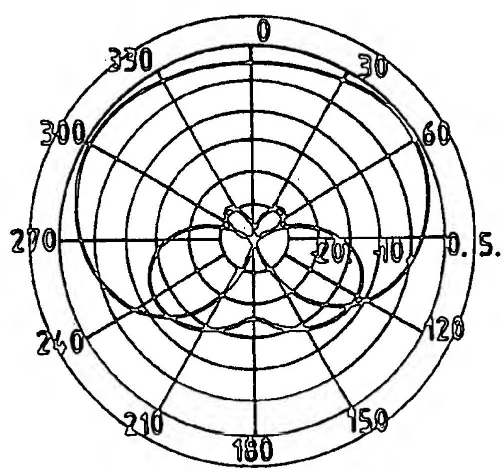


Fig. 8

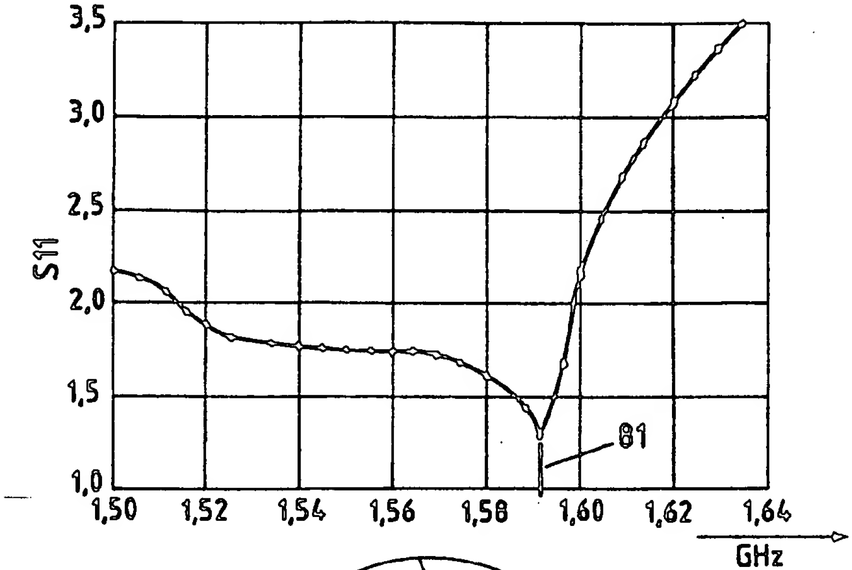


Fig. 9

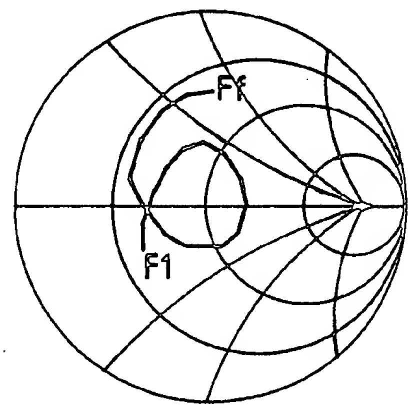
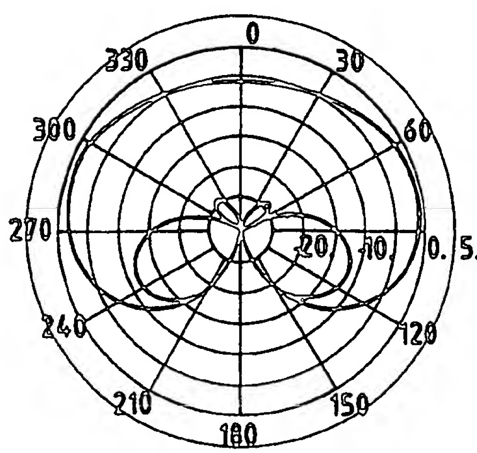


Fig. 10



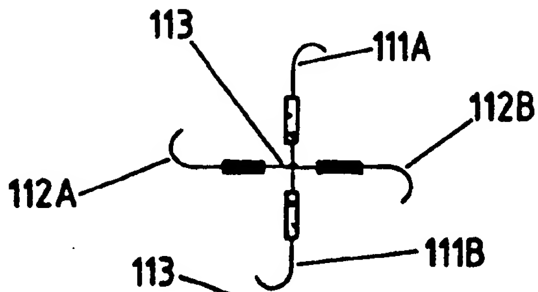


Fig. 11A
PRIOR ART

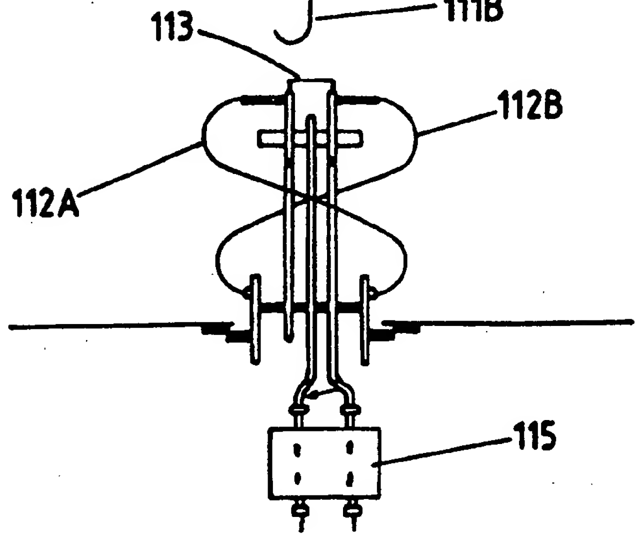


Fig. 11B
PRIOR ART

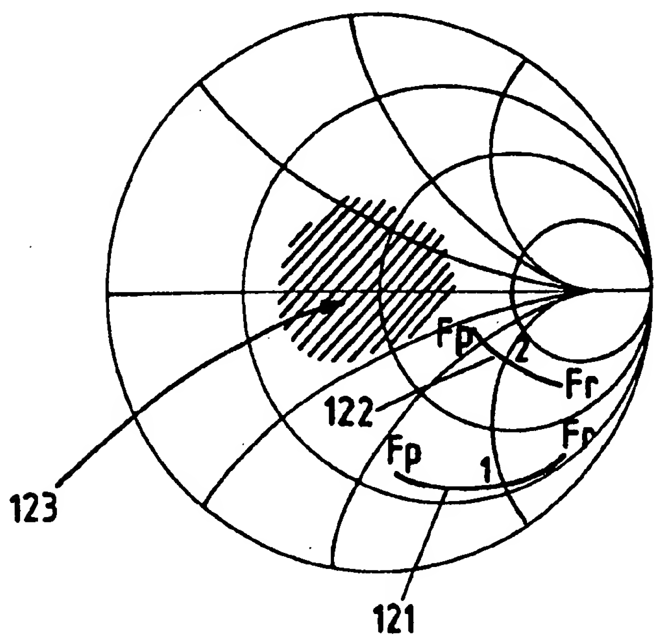


Fig. 12
PRIOR ART

DUAL LAYER RESONANT QUADRIFILAR HELIX ANTENNA

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention concerns a novel antenna structure, that has a quasi-hemispherical radiation pattern, and is capable of having a relatively wide passband, so as to make it possible, for example, to define two neighboring sub-bands therein.

This type of antenna can be applied, for example, in the context of satellite communications between fixed users and aeronautical, naval and land-based moving bodies. In this field, several satellite communications systems have been undergoing development in L band (for example INMARSAT, MSAT, PROSAT, NAVSTAR, G.P.S. etc.).

The first three systems referred to correspond to links with geostationary satellites. In these systems, the specifications of the antennas designed to fit out the moving bodies make it necessary for these antennas to have a radiation pattern with a quasi-hemispherical coverage, owing to very different incidences and or major variations in incidence of the received or transmitted signals.

Furthermore, the polarization of the antennas should be circular with an ellipticity of more than 5 dB (20 dB isolation) and special attention has to be paid to combating multiple-path phenomena for air and land-based moving bodies. This latter specification, moreover, makes it necessary for the preponderant component of the electrical field to be vertical for low elevations.

As for antennas which can be used at the reception of signals by transiting satellites used in systems of the U.S. NAVSTAR type, the specifications lay down that they should be operational in a passband of about 10% or in two neighboring sub-bands.

2. Description of the Prior Art

In the present state of the art, the only antenna structure compatible with this type of specification (essentially a quasi-hemispherical radiation pattern and circular polarization) is the resonant quadrifilar helix.

This type of known antenna, as shown in FIGS. 11A, 11B, is formed by two bifilar helices 111, 112, positioned orthogonally and excited in phase quadrature.

The exemplary structure shown in FIGS. 11A, 11B is cited in the work "UHF Satellite Array Nulls Adjacent Signals", Microwave & R.F., March 1984.

The antenna is the resonant quadrifilar helix with wires 111A, 111B; 112A, 112B short-circuited at their non-excited end 113. The passband is in the range of 10% with a 140% aperture at −3 DB for a wire length equal to $\lambda_o/2$ and a helical winding on a half turn. This type of antenna must not be mistaken for certain helical antennas of the type disclosed, for example, in the patent document U.S. Pat. No. 4,148,030 (FOLDES), the purpose of which is to provide highly directional (not quasi-hemispherical as in the invention) and high-gain axial radiation patterns. Their operation is of the travelling wave type, and they do not work in resonant mode. Moreover, these known antennas have a different structure. They have, in particular, a length that is several times the operating wavelength λ of the antenna. Besides, each helical wire is made of a plurality of resonating dipoles, to work at a specific frequency.

There is also another known embodiment of a quadrifilar helical antenna, used in INMARSAT STANDARD-C satellite communications between moving bod-

ies, where the antenna must work accurately in two sub-bands (1530–1545 MHz) and (1631.5–1646.5 MHz) corresponding respectively to reception and transmission (K. M. KEEN "Developing a Standard-C Antenna", M.S.N. Communications Technology, June 1988).

In this known embodiment, the antenna is a resonant quadrifilar helix with printed wires open at their non-excited end.

Although the resonant quadrifilar antennas meet the requisite specifications, they have a number of drawbacks.

The main problems posed by this known type of structure relate to the constraints of matching the impedance values of the antenna with those of the coaxial feed lines while, at the same time, achieving adequate excitation of the orthogonal bifilar helices.

In the narrow band systems, the feed/matching module may be positioned externally to the antenna, around the working frequency. But, when the antenna has to work in a wideband, as discussed herein, a feed/matching antenna internal to the antenna structure is generally used. The most common one is the so-called "balun" (sometimes also called a "symmetrizer") system or its variant, the "folded balun" with dissymmetrical input and symmetrical output.

An assembly such as this is shown in FIG. 11 where, taking account of the excitation and symmetry of structure of the antenna, the two orthogonal helices 111 and 112 have the same input impedance. Each bifilar helix 111A, 111B; 112A, 112B is fed by a folded balun type of coaxial symmetrizer. The two bifilars are then excited in phase quadrature by means of a hybrid coupler 115 (90°, −3 DB). Each coaxial (dissymmetrical) input therefore sees, in parallel, the impedance of the bifilar helix and a length adapter in the neighborhood of $\lambda/4$.

The symmetrizer/adapter assembly used in this type of antenna is made, for example, by means of a coaxial section with a length $\lambda/4$, the core and sheath of which form a dipole. To circumvent the problems due to the radiation from the sheath, the dipole may be enclosed between the core and an additional coaxial sheath (bazooka system) so as to prevent the flow of a current on the sheath of the coaxial line.

However, this type of assembly has the drawback of forming a sort of passband filter with a band that is still too narrow.

More complex systems were then conceived of, using a line compensated for by means of a solid conductor or, again, a dead coaxial cable forming a trap circuit (see C. C. Kilgus, "Resonant Quadrifilar Helix", Microwave Journal, December 1970).

In any case, a matching device must be added between the hybrid coupler and the "baluns" to match the antenna. This emerges clearly, in particular from the Smith pattern in FIG. 12 where it is clearly seen that, for two embodiments, the operating windows 121, 122 are essentially outside the matching zone 123.

Now, the use of matching devices introduces losses and often restricts the band of use of the antenna. Furthermore, in these exemplary embodiments, and certainly for reasons related to the space factor, the "folded balun" is placed in the very body of the antenna excited at its upper end. This then produces a disturbance by diffraction of the radiation patterns, particularly at the high frequencies.

It is an object of the invention to overcome these drawbacks.

More precisely, the invention provides a new antenna structure with an almost hemispherical radiation pattern and with circular polarization, notably (but not exclusively) in L Band.

Another aim of the invention is to provide a structure such as this, that avoids the need for introducing complex matching means between the antenna and its excitation.

It is also an aim of the invention to provide an antenna with a widening of the passband, or a dual frequency operation, notably either in a passband $\approx 10\%$ or in two neighboring passbands.

An additional object of the invention is to give a low-cost antenna with energy consumption compatible with the constraints of systems on board land-based, sea, air or space craft.

These aims, as well as others that shall appear here below, are achieved according to the invention by means of a resonant helical antenna with quasi-hemispherical radiation, of the type having a quadrifilar helix, formed by two bifilar helices arranged orthogonally and excited in phase quadrature, said antenna having at least one second quadrifilar helix that is coaxial and electromagnetically coupled with said first quadrifilar helix, each of said quadrifilar helices being wound around a distinct cylinder, with a constant radius.

The overlapping of these two resonant quadrifilar helices makes it possible to obtain a quasi-hemispherical radiation pattern over a wide frequency band, or over two neighboring frequency bands, depending on the settings chosen for their electromagnetic coupling.

Advantageously, the length of the wires is smaller than the wavelength λ of operation of said antenna, and is preferably between $\lambda/2$ and λ, so as to obtain the desired hemispherical pattern, with operation in standing wave mode.

According to a preferred characteristic of the invention, the wires of said second quadrifilar helix are in a position of precise or near radial overlapping, with the wires of said first quadrifilar helix.

According to another characteristic of the invention, said coupled quadrifilar helices are connected in parallel to a common feeder. Advantageously, said common feeder includes, firstly, a coupler element for the excitation, in phase quadrature, of the two orthogonal bifilar helices of each quadrifilar helix and, secondly, a symmetrizer element for the feeding, in phase opposition, of each of the wires of the bifilar helices.

Preferably, the wires of at least one of the two quadrifilar helices are open or short-circuited at their non-excited end.

Advantageously, at least one of the quadrifilar helices is made by means of printed circuit technology on dielectric support.

According to an advantageous characteristic of the invention, the coupling of said quadrifilar helices is controlled through at least one of the following means:

- checking of the radial divergence of overlapping of said quadrifilar helices;
- checking of the angular offset between said quadrifilar helices;
- checking of the helix pitch of each of said helices, in particular so as to match the impedance presented by each wire.

According to a first embodiment, said coupling of said quadrifilar helices is done so as to obtain a radiation of the antenna in a single wide passband.

According to a second embodiment, said coupling of said quadrifilar helices is done so as to obtain a radiation of the antenna in at least two passbands that are apart.

It is clear that, through the invention, the checking of the coupling can be optimized, without lowering any of the other characteristics of the antenna, and in particular the circular polarization and the radiation pattern.

BRIEF DESCRIPTION OF THE DRAWINGS

Other characteristics and advantages of the invention will appear from the following description of a preferred embodiment given as a non-restrictive illustration, and from the appended drawings wherein:

FIG. 1 is a view in perspective of an advantageous embodiment of a double helix quadrifilar antenna structure according to the invention;

FIG. 2 is a spread out view of one of the two overlapping quadrifilar helices, made in the form of printed copper strips on a kapton substrate;

FIG. 3 is a plane view of the base of the supporting cylinders of the antenna of FIGS. 1 and 2, bearing conductive connection segments of the radiating wires;

FIG. 4 gives a schematic view of a standard feeder structure for the antenna of FIGS. 1 to 3;

FIGS. 5, 6, 7 respectively represent the SMITH pattern, the value of the SWR and the radiation pattern in copolar and counterpolar circular polarization of a prototype of the invention dimensioned for dual band operation (dual frequency antenna).

FIGS. 8, 9, 10 respectively represent the SMITH pattern, the value of the SWR and the radiation pattern in copolar and counterpolar circular polarization of a prototype of the invention dimensioned for wideband operation.

FIGS. 11A, 11B and 12 respectively illustrate a front and top view and the Smith pattern of the impedance curve of a known type of monolayer quadrifilar helix.

DESCRIPTION OF PREFERRED EMBODIMENTS

A preferred embodiment of the antenna structure of the invention is shown in FIG. 1. It is formed by two concentric quadrifilar helices 11 and 12, wound around coaxial cylindrical insulator supports 13 and 14, with distinct diameters d_1, d_2. Clearly, the antenna structure of the invention can be extended to more than two concentric quadrifilar helices, in an obvious way. Each quadrifilar helix 11 and 12 has four wires 11_1, 11_2, 11_3, 11_4 and 12_1, 12_2, 12_3, 12_4 respectively, evenly spaced out and wound on the cylindrical supports 13, 14.

Each wire 11_1, 11_2, 11_3, 11_4; 12_1, 12_2, 12_3, 12_4 is formed by a continuous strip of electrically conductive material such as copper, with a width W, printed on a Kapton substrate, as shown in FIG. 2. The Kapton substrate may have a thickness of 50 μm for a copper strip width W of 35 μm.

The length of each wire is advantageously between $\lambda/2$ and λ and is, in any case, smaller than or equal to λ, so as to work in resonant mode and obtain a quasi-hemispherical radiation pattern.

When the wires have a length slightly higher than λ, a radial radiation pattern is obtained, and not a quasi-hemispherical one. This kind of pattern can however appear interesting, in some particular applications.

The four wires of each helix 11, 12 are open at each end 15 (upper end in FIGS. 1 and 2) and electrically connected to the other end 16 (lower end in FIGS. 1 and 2) with conductive segments 31, 32, 33, 34 positioned on the base 30 of the lower part 16 of the cylindrical supports 13, 14 as shown schematically in FIG. 3. These plane segments 31, 32, 33, 34 are advantageously formed by strips printed on Kapton, in the form of portions of segments with decreasing width from the edge up to the vicinity of the center of the base 30 of the cylinders 13, 14. Each of these conductive segments is connected to the central core of one of the four 50Ω feeder coaxial cables of the antenna structure. The two quadrifilar helices 11, 12 are thus parallel fed, wire to wire (11_1, 12_1; 11_2, 12_2; 11_3, 12_3; 11_4; 12_4).

The four wires of each helix 11, 12 are excited through the segments 31, 32, 33, 34 according to the feeder configuration shown schematically in FIG. 4, by means of a standard device formed by a hybrid coupler module 41 (3 dB, 90°) and two symmetrizer modules, 42, 43 (3 dB, 180°). One of the inputs, 41_1, 42_2, 43_3, of each of these modules 41, 42, 43 is connected to the ground through a 50Ω resistor 44. The coupler module 41 is positioned so that the two outputs 41_3, 42_4 feed the other input 42_2, 43_3 of the two modules 42, 43. The outputs at 180°, 42_3, 42_4 of the symmetrizers are connected so as to feed two segments 31, 34, the outputs at 0°, 42_4 and 43_3 exciting the other two segments 33, 34. In this way, we obtain an excitation in phase quadrature of the two bifilar helices 31, 33 and 32, 34 of each quadrifilar helix 11, 12 and an excitation in phase opposition of each of the wires 31 and 33, on the one hand, and 32 and 34, on the other hand, of each bifilar helix.

This assembly may be made compactly by means of printed technology, and may be placed directly at the base of the antenna structure.

In view of the value, close to 50Ω of the input impedance of each of the wires of the dual quadrifilar helical structure, no additional impedance matching is necessary.

Clearly, other configurations may be envisaged, as well as other technical means of implementation, as will be seen by those skilled in the art. Thus, in another embodiment of the excitation of the antenna structure (not shown) it is possible not to feed one of the two quadrifilar helices, which would then work as a stray element with respect to the second one.

The control of the coupling between the two quadrifilar helices can be done in many ways. It is notably possible to act on the radial divergence between the two helices, on the angular shift of the antennas around the axis of revolution of the antenna, with respect to a position of exact radial wire-to-wire overlapping, or again on the helix pitch of each of the helices.

The electromagnetic coupling of each impedance matched antenna wire, for example at 50Ω, is of course controlled so as not to damage, or so as to cause the least possible damage to, the other characteristics of the antenna, notably the circular polarization and the radiation pattern.

We shall now present the results obtained with two prototypes for implementing the antenna structure of the invention, corresponding respectively to a dual band configuration (FIG. 5, 6, 7) and to a wideband configuration (FIGS. 8, 9, 10).

Dual Frequency (or Dual Band) Antenna

In the first embodiment computed and tested, the antenna parameters are presented in the table I (with C: circumference; Le: length of a radiating wire; Lax: axial length; with reference to the notations of FIG. 2)

TABLE I

	internal helix	external helix
C	0.5 λo	0.57 λo
Le	0.74 λo	0.76 λo
Lax	0.58 λo	0.59 λo

A series of measurement readings was taken on each helix taken separately, then in simultaneous parallel feeding. Here below, the impedance presented is the impedance computed at the input of a radiating wire of the helix in the presence of the other ones, this impedance being half of that of a bifilary helix.

In the case of the measurements of the quadrifilar antennas taken separately, a reading was taken of a passband for a SWR<2 equal to 60 Mhz (internal antenna) and to 50 Mhz (external antenna).

The parallel feeding of the two helices leads to the impedance curve of the SMITH pattern of FIG. 5, where the curve represented for F1=1,480 to Ff=1,730 has two frequency bands 51, 52 that are apart in the matching region of the antenna. It is moreover possible, by means of an impedance transformer, to recenter the impedance curve on the chart. An adapted dimensioning of the parameter of the antenna also makes it possible to obtain a coincidence of the portions 51 and 52. The curve marks a double resonance owing to the coupling between the two quadrifilars. As can be seen in the SWR pattern of FIG. 6, the assembly works like two coupled resonant circuits, the coupling of which deflects the resonance frequencies 61, 62. The SWR is below 1.5 in two distinct frequency bands: 1.54 GHz<f<1.5666 Ghz and 1.602 Ghz<f<1.64 Ghz.

Furthermore, since the antenna is practically matched at 50Ω around the two resonance frequencies, the excitation device does not necessitate any specific assembly for additional matching. This frees the antenna from the drawbacks of the simple quadrifilar antenna.

FIG. 7 shows the radiation pattern of the coupled antenna, which differs little from the radiation patterns of the quadrifilar helices taken separately.

This embodiment can obviously be extended to more than two concentric quadrifilar helix, so as to obtain as many distinct passbands as there are distinct helix.

Wideband Antenna

By modifying the parameters of the antennas and the distance between the layers, the electromagnetic coupling between the two overlapping quadrifilar helices makes it possible to obtain a single passband that is wider than with a single-layer helix having the same parameters.

A configuration such as this is obtained, for example, by choosing the values of the parameters of table II.

TABLE II

	internal helix	external helix
C	0.34 λo	0.46 λo
Le	0.72 λo	0.75 λo
Lax	0.62 λo	0.65 λo

For these values of parameters, the initial passband is 65 Mhz for an SWR<2.5 for the internal antenna and SWR<2 for the external antenna.

In coupled operation, the passband for the dual layer antenna is equal to 86 MHz for an SWR<2. The corresponding SWR pattern and the Smith pattern of the impedance curve are shown in FIGS. 8 and 9.

The SWR is smaller than 1.75 on a continuous frequency band of 1.535 to 1.595 approximately, with a resonance curve of 1.59 Ghz. The impedance curve of FIG. 9 extends for F1=1.5 Ghz to Ff=1.63 Ghz practically integrally in the matching zone of the chart (with the possibility of more precise centering on the chart as for the previous embodiment).

Generally speaking, the structure of the antenna of the invention thus makes it possible to "reduce" the imaginary part of the impedance and bring its real part about 50Ω.

No substantial modifications are observed in the radiation patterns, FIG. 10 representing the pattern for the coupled dual layer antenna.

Owing to these characteristics, and owing to the possibility of the dual frequency, wideband embodiment, the antenna structure of the invention has many fields of application.

Thus it can be applied to satellite communications systems in L band currently being developed, for example those used by the "International Maritime Satellite Organization" (INMARSAT) in the field of worldwide maritime communications.

We can also cite systems in the U.S. such as the "Mobile Satellite System" (MSAT) which is carrying on the development of its own communications service for land-based vehicles. Similarly, different concepts have been proposed for air traffic communications and control (see J. Huang and D. Bell, "L-Band Satellite Communications Antennas for U.S. Coast Boats, Land Vehicles and Aircraft", IEEE, AP-S INT.SYMP. Digest 1987 (AP 22-1).

In Europe, the ESA (European Space Agency) program PROSAT is planning the development, for data transmission (PRODAT), of low G/T (−24 dB/K) terminals for air navigation (elevation between 10° and 90°), sea navigation (elevation between −25° and 90° to take account of +/−30° movements of the ship due to rolling and pitching) and land navigation (elevation between 15° and 90°) wherein the antenna structure of the invention finds advantageous application.

The implementation of the invention is clearly not restricted to these examples of use, and those skilled in the art will themselves be able to conceive of embodiments of the antenna other than those described herein, without going beyond the scope of the invention.

What is claimed is:

1. A resonant helical antenna with quasi-hemispherical radiation comprising at least two concentric quadrifilar helices, each of the quadrifilar helices comprising four wires arranged helically to define a cylinder of constant radius, the radius of each of the quadrifilar helices being unique, and each one of the quadrifilar helices formed of two bifilar helices arranged orthogonally and excited in phase quadrature, the quadrifilar helices being situated coaxially with respect to each other, the wires of the quadrifilar helices being positioned to substantially radially overlap each other for electromagnetically coupling the quadrifilar helices to improve the passband of the antenna.

2. An antenna according to claim 1, wherein the length of the wires forming each of said quadrifilar helices is smaller than the wavelength λ of operation of said antenna.

3. An antenna according to claim 2 wherein the length of the wires is comprised between λ/2 and λ.

4. An antenna according to claim 1 further comprising a common feeder to which said quadrifilar helices are connected in parallel.

5. An antenna according to claim 4, wherein said common feeder includes a coupler element for the excitation, in phase quadrature, of the two orthogonal bifilar helices of each quadrifilar helix and a symmetrizer element for feeding, in phase opposition, each of the wires of the bifilar helices.

6. An antenna according to claim 1, wherein the wires of at least one of the quadrifilar helices are open at their non-excited end.

7. An antenna according to claim 1, wherein the wires of at least one of the quadrifilar helices comprises strips of electrically conductive material printed on a dielectric support.

8. An antenna according to claim 1, wherein the electromagnetic coupling of said quadrifilar helices is controlled through at least one of the following means:

the radial divergence of overlapping of said quadrifilar helices;

the angular offset between said quadrifilar helices;

the pitch of each of said helices.

9. An antenna according to claim 1 wherein the wires of at least one of the quadrifilar helices are short-circuited at their non-excited end.

10. A resonant helical antenna with a quasi-hemispherical radiation pattern comprising:

at least two electromagnetically coupled concentric quadrifilar helices, each of the quadrifilar helices including four wires arranged helically to define a cylinder of unique constant radius, the wires of each of the quadrifilar helices forming two orthogonally arranged bifilar helices which are excited in phase quadrature; and

a common feeder connected to the wires of the quadrifilar helices in parallel, wire to wire.

11. A resonant helical antenna a quasi-hemispherical radiation pattern comprising:

at least two electromagnetically coupled concentric quadrifilar helices, each of the quadrifilar helices including four wires arranged helically to define a cylinder of unique constant radius, the wires of each of the quadrifilar helices forming two orthogonally arranged bifilar helices which are excited in phase quadrature; and

feeder means for connecting at least one, but less than all, of said quadrifilar helices in parallel wire to wire so that at least one of said quadrifilar helices operates as a stray element with respect to at least one other of said quadrifilar helices.

12. An antenna according to either claim 10 or 11 wherein the wires of said quadrifilar helices are situated in substantially radial overlapping position with respect to each other.

13. An antenna according to any of claims 1, 10 or 11 wherein the length of the wires forming said quadrifilar helices is about 0.75 λ.

14. An antenna according to any of claims 1, 10 or 11 wherein the axial length of the quadrifilar helices is between about 0.58 λ and 0.65 λ.

15. An antenna according to any of claims 1, 10 or 11 wherein the circumference of the quadrifilar helices is between about 0.34 λ and 0.57 λ.

* * * * *

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United States Patent [19]

Branson

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[45] Date of Patent: Mar. 2, 1993

[54] RADIO FREQUENCY APPARATUS

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[73] Assignee: Navstar Limited, United Kingdom

[21] Appl. No.: 735,881

[22] Filed: Jul. 25, 1991

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Apr. 29, 1991 [GB] United Kingdom 9109190

[51] Int. Cl.[5] H01Q 1/36; H01Q 21/20
[52] U.S. Cl. 343/895; 343/850
[58] Field of Search .... 343/895, 700 MS File, 343/850, 852, 878, 872

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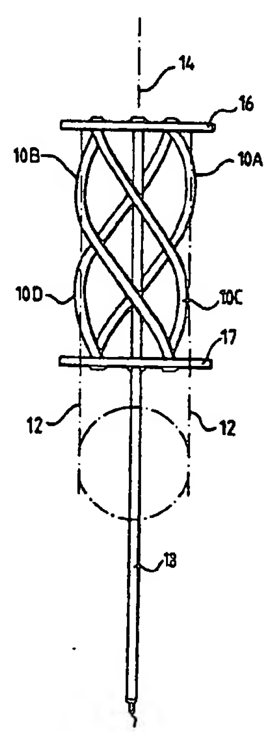
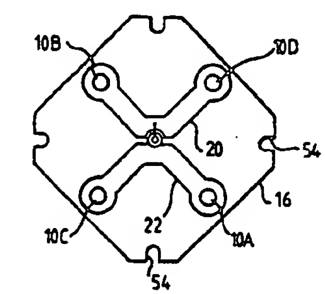
Assistant Examiner—Hoanganh Le
Attorney, Agent, or Firm—F. Eugene Davis, IV

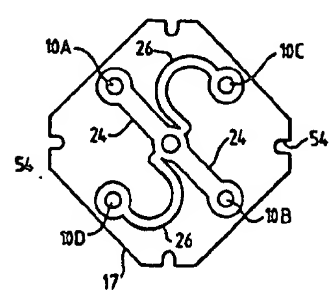
[57] ABSTRACT

A quadrifilar radio frequency antenna intended primarily for receiving signals from an earth orbiting satellite for navigation has four helical wire elements shaped and arranged so as to define a cylindrical envelope. The elements are co-extensive in the axial direction of the envelope and are mounted at their opposite ends in two printed circuit boards lying in spaced apart planes perpendicular to the axis with the end parts of the elements being soldered to conductor tracks on the boards, the tracks constituting impedance elements between the helical elements and between the helical elements and an axially located coaxial feeder. The conductor tracks are such that the effective length of one pair of helical elements and associated impedance elements is greater than that of the other pair and associated impedance elements. In this way, phase quadrature between the two pairs is obtained at the operating frequency without using differently shaped helical elements, and with little or no adjustment of the elements in the manufacturing process.

18 Claims, 3 Drawing Sheets







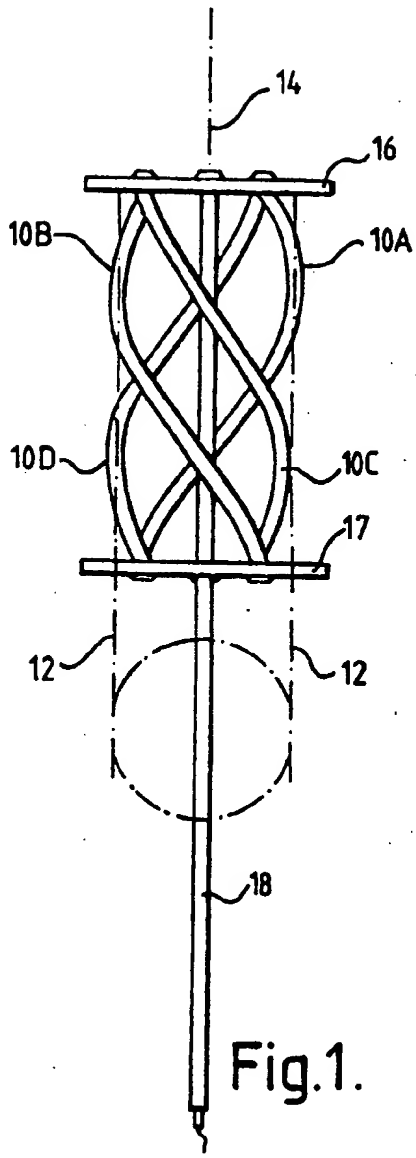


Fig.1.

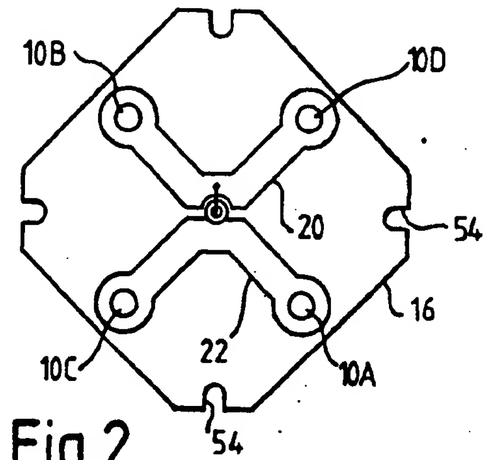


Fig.2.

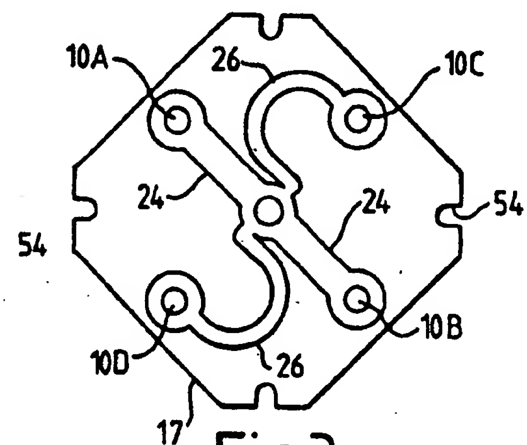


Fig.3.

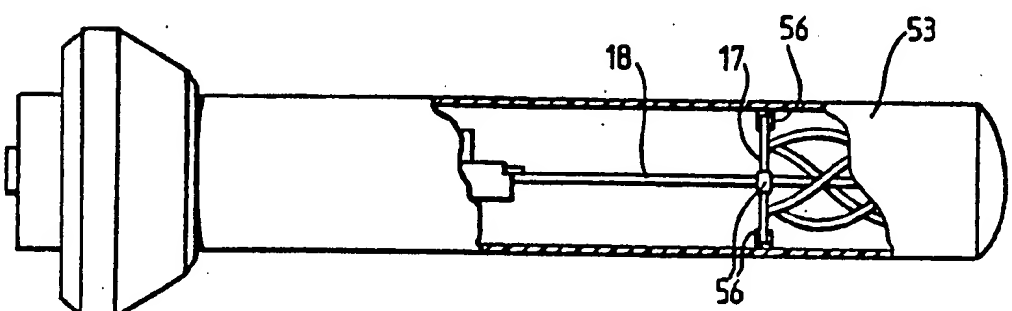


Fig.9.

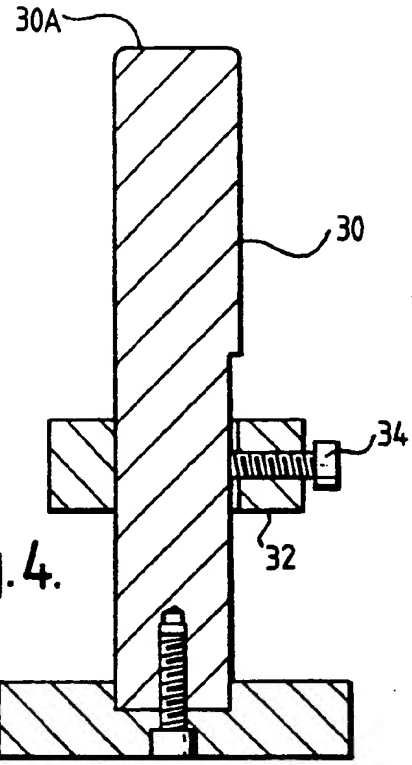
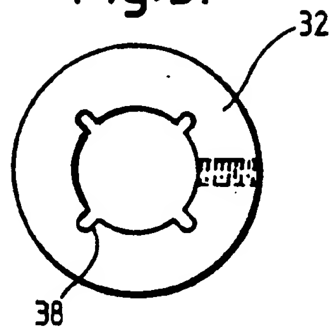


Fig.4.

Fig.5.


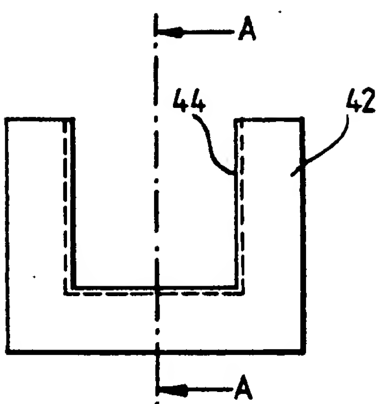


Fig.7.

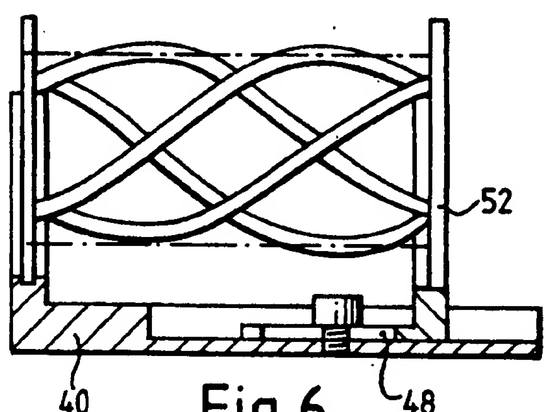


Fig.6.

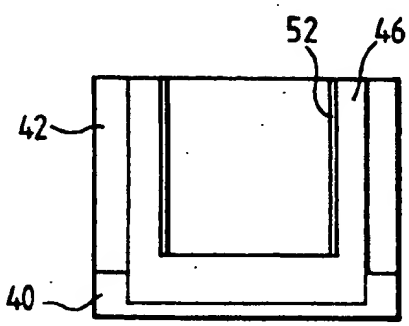


Fig. 8.

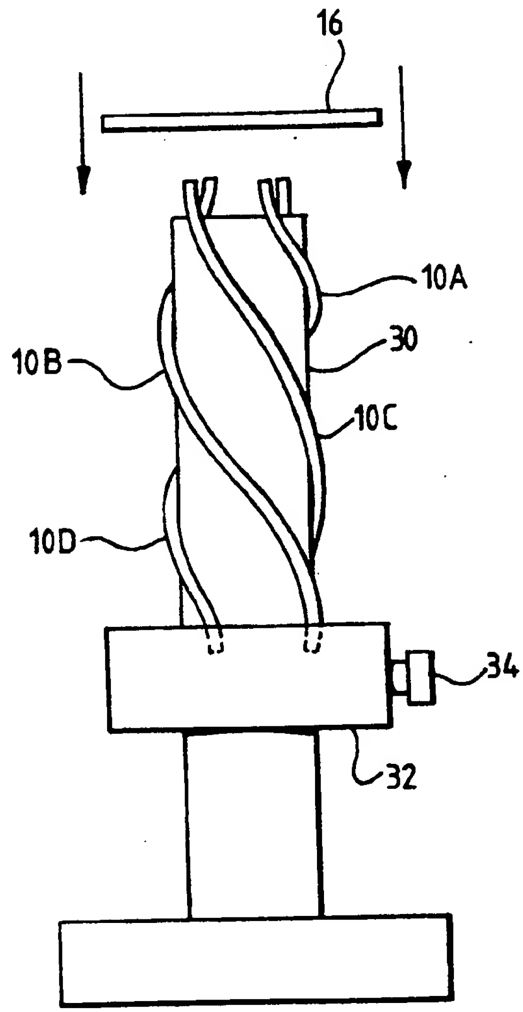


Fig.10.

RADIO FREQUENCY APPARATUS

FIELD OF THE INVENTION

This invention relates to a radio frequency antenna having a plurality of substantially helical elements, and to a method of manufacturing such an antenna.

BACKGROUND OF THE INVENTION

It is known that an antenna with a plurality of resonant helical elements arranged around a common axis can be made to exhibit a dome-shaped spatial response pattern which is particularly useful for receiving signals from satellites. Such an antenna is disclosed in "Multielement, Fractional Turn Helices" by C. C. Kilgus in IEEE Transactions on Antennas and Propagation, July 1968, pages 499 and 500. This paper teaches, in particular, that a quadrifilar helix antenna can exhibit a cardioid characteristic in an axial plane and be sensitive to circularly polarised emissions. The antenna comprises two bifilar helices arranged in phase quadrature and coupled to an axially located coaxial feeder via a split tube balun for impedance matching. While antennas based on this prior design are widely used because of the particular response pattern, they have the disadvantages that they are extremely difficult to adjust in order to achieve phase quadrature and impedance matching, due to their sensitivity to small variations in element length and other variables, and that the split tube balun is difficult to construct. As a result, their manufacture is a very skilled and expensive process.

It is an object of this invention to provide an antenna which achieves similar performance to those of the prior art at lower cost.

SUMMARY OF THE INVENTION

According to a first aspect of this invention, a radio frequency antenna comprises a plurality of helical elements arranged around a common axis, a substantially axially located feeder structure, and a plurality of separately formed coupling elements forming conductive paths between the helical elements and the axis. The coupling elements are preferably located at the ends of the helical elements in the form of, for instance, radially extending conductors connecting those ends to the feeder structure. Such coupling elements may be located at one or both ends of each helical element, and may be radially directed or may follow a longer path between the respective elements and the axis. Arranging for the coupling elements to have different electrical lengths is one way of providing different coupling impedances for respective helical elements so that, for example, an antenna can have differently phased pairs of helical elements. In particular, the helical elements may be supported by two spaced apart insulative and preferably planar mounting members such as printed circuit boards extending perpendicularly to the common axis, the coupling elements being conductive tracks formed on one or both boards. Alternatively wire loops may be used for the coupling elements. By forming the coupling elements and the mounting members separately from the helical elements, both can be relatively accurately formed with predetermined shapes and dimensions so that, when assembled together, relatively little, if any, adjustment is required to obtain an antenna having the required characteristics. In this way, much of the need for skill and time in manufacturing and adjusting the prior art antennas is avoided. In the preferred embodiment of the invention, the helical elements are simple helical lengths of copper wire all of the same dimensions and each with no more than very small end portions which depart from the helical path, while the impedance elements are printed circuit tracks of fixed shapes and dimensions. Both types of elements can, as a result, be mass-produced to precise dimensions.

In one preferred embodiment of the invention each helical element executes a half turn around a cylindrical envelope, but other fractional turn elements may be used in other embodiments, and indeed it is possible to use elements having more than one turn.

The preferred embodiment of the invention is a quadrifilar antenna in that it has four helical elements arranged so as to define a cylindrical envelope centred on the common axis, the elements all having the same diameter and being coextensive in the axial direction. They are mounted at opposite ends in two printed circuit boards lying in spaced apart planes perpendicular to the axis, the end parts of the elements being located in holes in the boards where they are soldered to printed conductors running between the holes and the axis. On one board the conductors are connected to the end of a feeder, two of the elements being thereby connected to one conductor of the feeder, and the other two being connected to the other feeder conductor, the feeder preferably being of coaxial type. On the other board the elements are linked to a common connection on the axis, but here the conductors from two of the elements are longer than the conductors from the other two elements the length difference being such that at the operating frequency, one pair of helical elements operates 90° out of phase with respect to the other pair.

The axial length of the helical elements (which is the distance between the outer surfaces of the printed circuit boards in the preferred embodiment) is preferably in the range 0.25λ to 0.40λ where λ is the operating wavelength, while the diameter is typically between 0.08λ and 0.18λ. From a ratio aspect, the ratio of the element length to element diameter may typically be in the range of 1.25 to 3.5, with the range of 2.0 to 3.0 being preferred. The thickness of the helical elements affects the bandwidth of the antenna. In the preferred embodiment the elements are about 0.01λ thickness.

The difference in length between the conductors on the said other printed circuit board may be achieved by forming the conductors for one pair of helical element as straight radial tracks, but the conductors for the other pair as longer tracks between the axis and the ends of the respective helical elements. These longer tracks may take the form of loops or be meandered, for example. Thus, the longer tracks may comprise two semi-circular loops each having an inner radius of 0.020λ to 0.025λ and width of 0.005λ to 0.010λ.

For mechanical strength, it is advantageous to mount both printed circuit boards on the feeder, with the feeder running from its connections on the one board axially through the antenna and through the other board to a termination spaced some distance along the axis from the helical elements. It is then possible to form the common connection of the conductors on the board opposite the feed end as a printed ring around the feeder which may soldered to the feeder screen conductor. In this case the antenna thus consists of no more than the helical wire elements, two printed circuit boards, and a semi-rigid or rigid coaxial feeder. If protection from the weather is required, the antenna may additionally in-

clude a radome. In the preferred embodiment this is a plastics tube with an end cap.

Alternative embodiments within the scope of the invention include an antenna having radiating elements which are helical in the sense that they each form a coil or part coil around an axis but also change in diameter from one end to the other. For example, while the preferred embodiment has helical elements defining a cylindrical envelope, it is possible to have elements defining instead a conical envelope or another surface of revolution. The invention also includes an antenna in which the helical elements are supported by alternative separately formed elements connected to the feeder structure. For instance, one of the supporting elements may be insulative, while another may be wholly conductive. Thus, the helical elements may each have one end mounted in an insulative printed circuit board having conductive tracks connecting the elements to the feeder structure, while their other ends may be mounted in a metallic plate or a board having a continuous plated layer. Alternatively, the helical elements may be so mounted that each has one of its ends insulated from the feeder structure.

According to a second aspect of the invention, there is provided a method of making a radio frequency antenna which has a plurality of helical elements arranged around a common axis, a substantially axially located feeder structure, and at least two mounting members at least one of which is insulative and bears coupling elements forming radio frequency conductive paths between the helical elements and the axis, wherein the method comprises: locating the helical elements with their axes coincident and with their respective ends lying in two spaced apart planes perpendicular to the common axis; securing a first of the mounting members to the helical element ends in one of the planes; bringing together the second of the mounting members and the assembly of the first mounting member and the helical elements so that the second mounting member is in a predetermined position parallel to and axially spaced from the first mounting member in which it is located on the other ends of the helical elements; securing the said other mounting member to the said other ends; and attaching the feeder structure to one or both mounting members. The feeder structure may be attached to one or both mounting members before or after bringing the said other mounting member into position on the helical elements.

In the preferred method, the helical elements are located around a cylindrical mandrel with one end of each element projecting beyond the end of the mandrel, and they are held against the mandrel by an outer tube. The first mounting member is then placed on the projecting ends and the conductors on the member are soldered to the ends. The assembly is removed from the mandrel and placed in a jig which has two parts slidable relative to each other. The first mounting member is fitted into one part of the jig and the second mounting member into the other. The jig is arranged such the mounting members can be moved towards each other in an axial direction by sliding the jig parts, but, in the required relative positions at least, they are held perpendicular to the common axis and at fixed rotational positions with respect to each other. This means that when the second mounting member is brought onto the unattached ends of the helical elements, it is in the precise required relationship with the first mounting member before it is secured. The conductors on the second mounting member are then soldered to the helical element ends, and the feeder structure is also soldered to the members. The resulting antenna is then removed from the jig.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described by way of example with reference to the drawings in which:

FIG. 1 is a side elevation of a quadrifilar helical antenna in accordance with the invention;

FIG. 2 is a top plan view of the antenna of FIG. 1;

FIG. 3 is a bottom plan view of the antenna of FIG. 1;

FIG. 4 is a sectional side elevation of a first jig for manufacturing the antenna;

FIG. 5 is a plan view of collar element of the jig of FIG. 4;

FIG. 6 is a sectioned side elevation of a second jig for manufacturing the antenna viewed on the line A—A in FIG. 7 showing parts for the antenna of FIG. 1 fitted in the jig;

FIG. 7 is an end elevation of part of the second jig;

FIG. 8 is an end elevation of another part of the second jig;

FIG. 9 is a fragmentary side elevation of the combination of the antenna of FIG. 1 mounted in a radome; and

FIG. 10 is a side elevation of the first jig for manufacturing the antenna, showing helical elements of the antenna mounted on the jig.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1 of the drawings, a quadrifilar antenna has four helical elements 10A, 10B, 10C, and 10D of equal length and each bent to form a half turn around a cylindrical envelope (shown by the chain lines 12). The elements 10A to 10D are thus spaced at a constant radius from a common central axis 14, and they are arranged so as to be coextensive in an axial direction. Two mounting members in the form of a pair of printed circuit boards 16, 17 spaced apart and lying perpendicular to the axis 14 serve to support the respective ends of the helical elements 10A to 10D, and a rigid coaxial feeder 18 is secured at the centre of both boards, and runs axially between the boards and below the second board 17 to a termination (not shown) some distance from the helical elements.

As will be seen from FIGS. 2 and 3, the printed circuit boards 16, 17 bear coupling elements in the form of plated conductors 20, 22, 24, 26 which connect the ends of the helical elements 10A to 10D to the feeder 18 on the board 16, and with each other on the board 17. In practice, the boards 16, 17 have holes drilled through them to receive the ends of the helical elements 10A to 10D and the feeder 18, and the connections are made by soldering on those faces of the boards 16, 17 which face away from each other. Referring to FIG. 2, the inner conductor of the coaxial feeder 18 is connected to a V-shaped plated conductor 20 on the board 16 and the ends of the arms of the V are connected to the upper ends of the helical elements 10B and 10D, these ends being spaced apart around the circumference of the cylinder 12 by 90°. The screen of the feeder 18 is connected to a similar V-shaped conductor 22 which is formed as a virtual mirror image of the conductor 20 and is connected to the upper ends of the helical elements 10A and 10C. By following the path of the ele-

ment 10A in FIG. 1 and then referring to FIG. 3 it will be seen that the lower end of element 10A penetrates the lower printed circuit board 17 at a position diametrically opposite the position of its upper end and at the end of one of a pair of oppositely located radial conductors 24 plated on the lower board 17. The other radial conductor 24 is connected to the lower end of element 10B whose upper end is connected to the inner conductor of the feeder via conductor 20 on the upper board 16. As a result, the helical elements 10A and 10B, portions of the conductors 20 and 22 and the conductors 24 together form a helical loop having one side connected to the inner conductor of the feeder 18 and the other side connected to the feeder outer screen. By comparing FIGS. 1, 2, and 3, a similar helical loop can be identified comprising helical elements 10C, 10D, the other parts of conductors 20 and 22, and looped conductors 26 on the lower board 17. Again, this second helical loop has one side connected to the inner conductor of the feeder 18 and the other side connected to the feeder outer screen.

It is important to note, that while the dimensions of the helical elements 10C and 10D are the same as the elements 10A and 10B, the presence of the looped or curved conductors 26 on the lower board 17 gives the second loop greater length than the first. It follows that the resonant frequency of the second loop is below that of the first. Consequently, at the end of the feeder 18 where it meets the board 16, signals in the first loop at a frequency midway between the two resonant frequencies will appear at the end of the feeder, out of phase with signals at the same frequency in the second loop. The dimensions of the looped conductors 26 in relation to the dimensions of the other elements of the helical loops are such that the phase difference is substantially 90°. It is this property of a phase shift between the pairs of helical elements that gives the antenna a cardioid response in space at the centre frequency, the peak of the response occurring at the zenith, i.e. on the axis 14 in a direction opposite to that of the feeder 18. As shown, the antenna is sensitive to right hand circularly polarized signals and tends to reject left hand polarised signals. By rotating either of the printed circuit boards 16, 17 through 90° about the axis so that the arrangement of the connections of the elements 10A to 10D is altered and altering the direction of rotation of these elements, the antenna can be made to be sensitive to left hand circularly polarized signals.

The feeder 18 is preferably made form so-called semi-rigid coaxial cable so that the antenna can, to a degree, be made self-supporting. In the preferred embodiment, the feeder cable has a characteristic impedance of 50 ohms, and the dimensions of the helical elements, particularly their length and thickness, and the lengths and thickness of the conductors on the printed circuit boards 16, 17 are chosen to produce a matching 50 phms antenna impedance at the centre frequency.

Taking as an example an antenna for L-band GPS reception at 1575 MHz, the axial length and thickness of the helical elements 10A to 10D are approximately 60 mm and 2.0 mm respectively. The diameter of the cylindrical envelope 12 is approximately 23 mm, and the lengths of the conductors on the printed circuit boards 16, 17 are such that the effective electrical length of each loop is approximately half of the wave-length at the respective resonant frequency.

In this example, it has been found that the required 90° phase difference can be obtained if the loops of the conductors 26 have an inside radius of about 4.19 mm and a width of about 1.52 mm. The other printed conductors are 3.05 mm wide.

Characteristic impedances other than 50 ohms may be obtained at the end of the feeder 18 by varying the length and spacing of the conductive parts comprising the helical elements and the printed circuit board conductors. Indeed, fine adjustments can be made during assembly by rotating the lower printed circuit board 17 by a few degrees one way or the other on the feeder prior to soldering it to the conductors 24 and 26. Rotating the board one way causes the diameter of the helical elements to be reduced and the spacing between the boards to be increased, while rotating it the other way increases the diameter and reduces the spacing. In this way, the matching of the antenna and the adjustment of its centre frequency can be optimised.

As mentioned hereinbefore, forming the elements 10A to 10D as simple helices considerably aids the ease with which the antenna can be manufactured. In practice, each helical element is formed with a small end part (not shown) which deviates from the helical path and is parallel to the central axis. This allows each helical element to be fitted easily and accurately in the predrilled and equally circumferentially spaced holes in the boards 16 and 17. In the preferred antenna, no other deviations from the helical path are required. The helical elements can, as a result, be constructed to relatively close tolerances. It is well known that conductors formed on printed circuit boards by photographic techniques can be produced to extremely close tolerances. Consequently, all parts of the two loops making up the antenna can be produced accurately to yield assemblies which show a high degree of repeatability in production, to the extent that the only adjustment required to meet a specification similar to that achieved by prior art antennas is a small rotation of one board with respect to the other as mentioned above while monitoring the variation of the standing wave ratio of a signal applied to the lower end of the feeder at the centre frequency.

The method of manufacturing the antenna will now be described with reference to FIGS. 4 to 8 and 10.

The helical elements are formed by winding copper wire around a cylindrical former (not shown) having helical groves. The former is of a size such that, initially, the wire is wound to a slightly smaller diameter than the required diameter so that it springs back to the required diameter when removed from the former.

Having produced in this way four helical elements of the required length and with end parts bent to lie parallel to the central axis, these four elements are placed in a first jig illustrated in FIGS. 4 and 5 in the manner shown in FIG. 10. This jig comprises a central mandrel 30 and a vertically slidable collar 32 having a grub screw 34 for engaging a flat 36 cut in the side of the cylindrical mandrel 30. By forming four equally spaced grooves 38 parallel to the axis in the interior surface of the collar 32, as shown in FIG. 5, the helical elements may be located around the mandrel 30 with, in each case, one end located in a respective groove 38 so that the elements are equally spaced around the mandrel and are coextensive lengthwise. The height of the collar 32 is set such that the other end parts of the helical elements, and only those parts, project above the top face 30A of the mandrel 30. Next, a tube (not shown) is placed over the helical elements around the mandrel 30. This tube is a tight fit so that the helical elements are held tightly in place. With the elements so held, one of